New Petrological and Geochemical Data on Easter Island

P.De Paepe & I. Vergauwen†*

Introduction

A joint *Belgian-Chilean biological mission*, conceived and headed by Prof. H. Dumont of the Department of Morphology, Systematics and Ecology of the Gent University, spent about five weeks on Easter Island in August and September 1990. The project was undertaken specifically to obtain a reasonably complete picture of the palaeoenvironmental evolution of the region during the Holocene. For that purpose coring was successfully applied to sample sediments deposited on the bottom of the fresh water crater lake of Rano Raraku in view of detailed biological and ecological research.

In order to facilitate the interpretation of the data emerging from the study of the uncovered lake sediments, the authors of the present study were asked to sample (P.D.P.) and analyse petrographically and geochemically (I.V./P.D.P.) a limited number of lava flows and pyroclastics exposed on the island, in particular in the surroundings of Rano Raraku and Poike. The following account, which is based on fifty-seven lavas and three hydroclastic rocks, summarizes the first results of our laboratory study.

Abundances of major, trace and rare-earth (RE) elements were determined by inductively coupled plasma atomic emission spectrometry at the Département des Sciences de la Terre of the Université de Bretagne Occidentale (UBO) in Brest (France). This was done by I.V., in close collaboration with J.Cotten. Microprobe analyses were carried out at the Institut Français de Recherche pour l'Exploitation de la Mer (Ifremer) in Plouzané, Brest (I.V./P.D.P.). In addition, a few rocks were selected for geochronological work at the Free University of Brussels (Belgium). For the time being two new K-Ar datings of younger lava flows encircling the Rano Raraku edifice are available. They are reported and discussed in a companion paper (this issue).

Our data complement the results of previous petrological studies (Bandy 1937; Baker et al. 1974; González-Ferrán & Baker 1974; Clark & Dymond 1977; Bonatti et al. 1977; Baker 1993), document the phase chemistry of nineteen representative lava flows and tuffs, and draw the attention to the rather unusual rare-earth element and yttrium patterns displayed by some rock specimens collected on the slopes of Poike and Rano Kau. The study of both the source and the mechanisms that gave rise to such abnormal geochemical properties, as well as that of the mantle heterogeneity below the island are still in progress. The discussion of these aspects of our research will therefore not be included in this paper.

Nomenclature and petrography

Fig.1 is a sketch map of Easter Island showing the geographical location of the rocks studied. Only specimens mentioned explicitly in the text, tables or figures are marked with their field number.

Using a total alkalis versus silica (TAS) diagram for rock classification and nomenclature (Le Maître et al. 1989) the analysed lava samples should be referred to as basalt (47), hawaiite (1), mugearite (3), benmoreite (3) and comenditic rhyolite (3). As basalt is by far the dominant rock type (47 on a total of 57 specimens) rocks of basaltic composition were further subdivided into basalts s.s. and hawaiitic basalts on the basis of Differentiation Index (DI) and normative plagioclase. The former are typified by a DI lower than 30, in combination with a normative plagioclase having an anorthite content of at least 50 per cent. The latter have a DI ranging from 30 to 35 and contain calcic andesine as normative plagioclase.

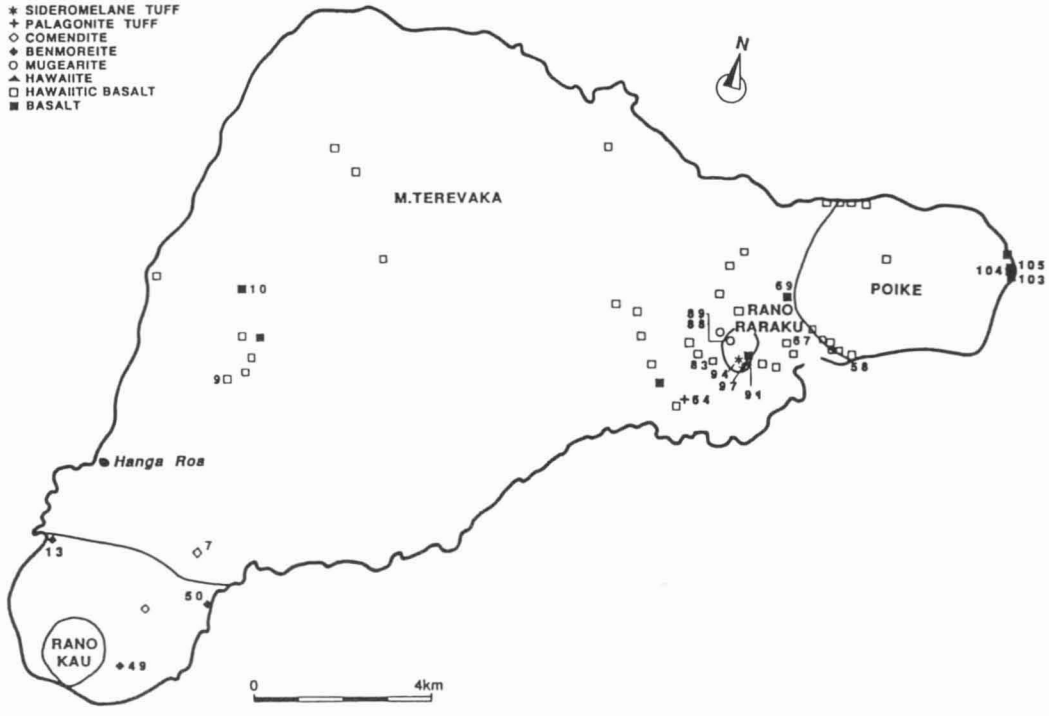

Figure 1. Sketch map of Easter Island, showing location and name of the rock samples studied

According to their ratios of normative diopside, olivine, hypersthene, nepheline, or quartz, it appears that all examined basaltic rocks have tholeiitic affinities (fig.2). To construct the

Ne-Ol-Di-Hy-Qz classification diagram, analyses were recalculated to 100 percent water-free and CIPW norms were obtained using a uniform oxidation ratio ($Fe_2O_3/FeO = 0.15$). The analysed quartz tholeiites fall in a narrow field with a small amount of normative quartz, whereas olivine tholeiites occupy a position in between the Di-Hy tie line and the critical plane of silica undersaturation. Fig.2 accentuates a key feature about the samples coming from the Roiho area. These olivine tholeiitic basalts are thought to have been poured out during a relatively late volcanic episode in the evolution of Maunga Terevaka. They plot much closer to the critical plane of silica undersaturation than most examined basaltic lavas of Easter Island do. This is in perfect agreement with data reported in previous publications (Baker et al. 1974; Clark & Dymond 1977; Bonatti et al. 1977).

Moderately and strongly differentiated volcanic rock types are poorly represented in our collection. In a TAS diagram the intermediate members of the Easter Island volcanic series generally plot a little above the empirical boundary that separates rocks with tholeiitic chemistry from those of alkaline parentage. The alkaline character of the intermediate lavas is thus not very pronounced and for that reason the rock suite of Easter Island is traditionally known as being a transitional one. This is also supported by the trend of the rock sequence on an AFM variation diagram (fig.3), that shows the relative proportions of alkalis ($Na_2O + K_2O$), iron oxides (FeO + Fe_2O_3) and magnesia (MgO). On this diagram all of the intermediate rock samples under study are characterized by a rather moderate iron enrichment.

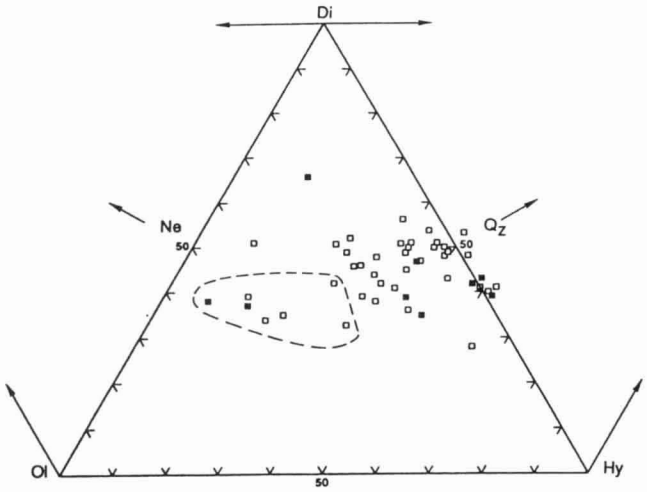

Figure 2. CIPW normative compositions of basalts s.s. (black squares) and hawaiitic basalts (open squares) from Easter Island plotted in the system Ne-Ol-Di-Hy-Qz. A dashed line encircles the rock samples collected in the Roiho area.

Basalts *s.s.* (9 specimens in total) usually contain phenocrysts and/or microphenocrysts of plagioclase. Their sizes vary, from as small as 0.5 mm up to 1 cm, and many show evidence of corrosion and clouding. Some rock specimens carry only very small quantities of phenocrysts of this mineral; in others they occur in moderate to high proportions. They may coexist with sparse microphenocrysts of olivine and/or augite. The phases of the groundmass invariably include plagioclase, clinopyroxene, Fe-Ti oxides (magnetite, titanomagnetite and ilmenite), and varying amounts of olivine and brown volcanic glass, the chief rock textures being intergranular and intersertal. The analysed basalts s.s. show no petrographic evidence of vesicle filling but in most of them the olivine crystals are marked by a low degree of iddingsitization.

Similarly, the majority of the hawaiitic basalts (38 samples) are sparsely to moderately phyric and exhibit various phenocryst/microphenocryst assemblages, with plagioclase-phyric and plagioclase-olivine-phyric types being the most abundant. Aphyric samples appear to be particularly abundant in the Roiho region. The textures and mineralogies of hawaiitic basalts are not fundamentally different from those characterizing basalts s.s. However, it should be mentioned that two lava flows emplaced near the top of Maunga Terevaka contain a minor amount of phlogopite in their groundmass and that several rocks from Anakena, Roiho and the neighbourhood of Rano Raraku carry vesicles which are partially or completely filled with opal.

All examined lavas intermediate in composition between hawaiitic basalt and benmoreite (i.e. hawaiite and mugearite) are extremely fine-grained, non-vesicular, almost aphyric, with either intergranular, trachytic or intersertal textures. The sparse microphenocryts that appear scattered randomly in these slightly to moderately differentiated rocks invariably consist of plagioclase. Many prismatic apatite crystals are embedded in a mugearitic rock specimen than we sampled close to the Rano Raraku crater.

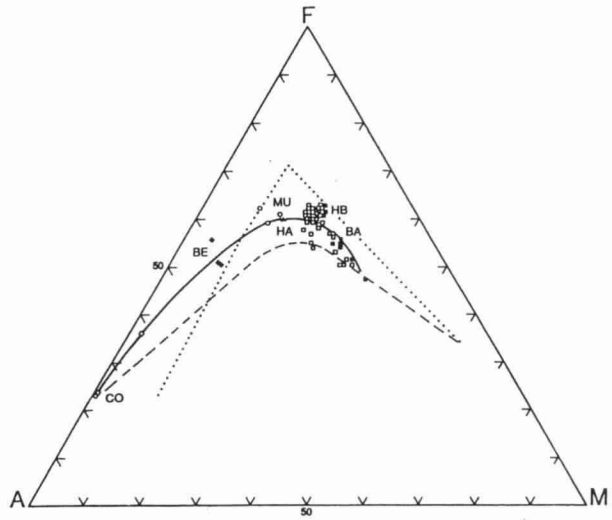

Figure 3. An AFM diagram for all of the analysed rocks from Easter Island. The trend for Easter Island (heavy line) is compared to trends for typical Hawaiian tholeiitic (dotted line) and alkaline (dashed line) sequences (after MacDonald & Katsura, 1964). Abbreviations are as follows: BA: basalt s.s.; HB: hawaiitic basalt; HA: hawaiite; MU: mugearite; BE: benmoreite; CO: comendite.

Benmoreitic flows are aphyric or moderately phyric and usually display low vesiculation. Microphenocryst minerals include plagioclase, clinopyroxene, olivine and ore minerals, plagioclase being the most widespread type. Olivine, if pre-

sent, is always a minor constituent. Several benmoreites contain a dark brown glass phase. A rock sample coming from the steep sea-cliffs developed at Vinapu (RN50) has a prominent brecciated appearance and this structural feature is interpreted

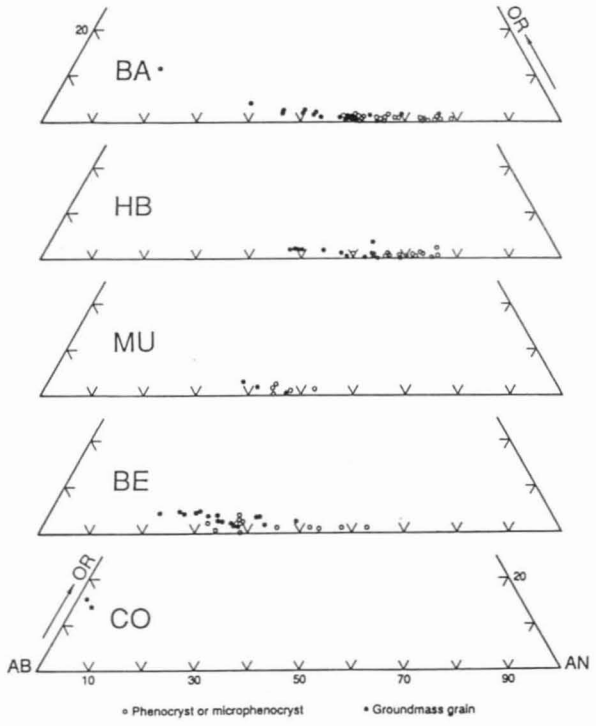

Figure 4. Plots of plagioclase compositions showing molar anorthite, albite, and orthoclase components for minerals from various lavas from Easter Island. Abbreviations as in fig.3.

as being produced by magma mixing. Unequivocal evidence for magma mixing is provided by microprobe analysis that points to the presence of (a) two compositionally distinct volcanic glass phases, one in the relatively fine-grained hyalopilitic host rock and another in the much coarser rock fraction, and (b) phenocrysts and microlites of plagioclase, pyroxene and olivine of strongly contrasting composition (see Section 3.).

The comenditic rhyolites originating from Maunga Orito and Maunga Te Manavai consist for more than 80 per cent of anhydrous glass and exhibit typical spherulitic textures. The spherical bodies are enclosed by a glassy matrix with traces of flow banding, containing scarce euhedral zircon crystals and variable proportions of swallow-tailed microlites and crystallites of alkali feldspar and pyroxene. Occasionally, we also noted some iron oxide grains in these highly silicic rocks.

Phase chemistry

Compositions of felsic and mafic mineral phases, and of natural glasses occurring in nineteen samples chosen to be representative of the Easter Island volcanic rock series, are presented and concisely discussed in this section. On the understanding, however, that due to a faulty numbering during the manufacture of the thin sections to be submitted to microanalysis, data connected with hawaiite cannot be provided for the mùoment. Until now, no comprehensive study of phase chemistries of lavas and tephra from Easter Island has been published.

Plagioclase is the principal mineral phase in all samples studied. Representative plagioclase compositions are given in Table 1. A plot of all available analyses, showing molar anorthite, albite and orthoclase components for phenocrysts/micro-phenocrysts and groundmass grains occurring in each of the five main rock classes, is presented in fig.4. There is a continuum of decreasing anorthite content with increasing degree of differentiation. It is now definitely established that plagioclases of basalts s.s. and hawaiitic basalts are compositionally equivalent. Many plagioclase phenocryst compositions refering to benmoreites are more sodic than coexisting groundmass grains of the same mineral. This supports the hypothesis uttered above that at least two benmoreites available for the present study result from a process of magma mixing. Note also that the increase of the orthoclase

Table 1
Representative analyses (in wt.%) of feldspars from various rocks from Easter Island

	a	b	c	d	e
SiO_2	49.39	50.93	57.26	59.06	67.82
TiO_2	0.59	0.32	0.03	0.05	0.10
Al_2O_3	31.32	30.52	27.13	25.37	19.41
FeO	0.56	0.71	0.28	0.38	0.52
MnO	0.12	-	0.08	-	0.05
Cr_2O_3	0.13	-	-	-	0.07
MgO	0.18	0.16	0.07	0.01	-
CaO	14.41	14.01	9.13	7.67	0.71
Na_2O	2.85	3.59	6.25	6.99	9.60
K_2O	0.20	0.18	0.24	0.44	2.47
Total	99.75	100.42	100.47	99.97	100.75
numbers of ions on the basis of 32 oxygens					
Si	9.06	9.27	10.24	10.58	11.90
Ti	0.08	0.04	-	0.01	0.01
Al	6.78	6.55	5.72	5.36	4.02
Fe^{2+}	0.09	0.11	0.04	0.06	0.08
Mn	0.02	-	0.01	-	0.01
Cr	0.02	-	-	-	0.01
Mg	0.05	0.04	0.02	-	-
Ca	2.83	2.73	1.75	1.47	0.13
Na	1.01	1.27	2.17	2.43	3.27
K	0.05	0.04	0.05	0.10	0.55
Z	15.90	15.86	15.96	15.95	15.93
X	3.89	4.04	3.97	4.00	3.95
%Ca	72.8	67.6	44.1	36.8	3.4
%Na	26.0	31.4	54.6	60.7	82.6
%K	1.2	1.0	1.4	2.5	14.0

a. Bytownite phenocryst in olivine tholeiite RN69
b. Labradorite microphenocryst in hawaiitic basalt RN58
c. Andesine microphenocryst in mugearite RN89
d. Andesine phenocryst in benmoreite RN50
e. Anorthoclase microlite in comendite RN7
Dashes mean below detection limits

component is controlled by the evolving magma chemistry.

Clinopyroxene is another very common rock-forming constituent. Representative analyses are listed in Table 2 and com-positional variations in terms of quadrilateral components (En, Wo, Fs) are shown diagrammatically in fig.5. Clinopyroxene microphenocrysts exhibit a great compositional variability and span the augite and ferroaugite fields. In basalts s.s. some of them plot close to or even within the fields assigned to salite and endiopside, respectively. In relation to coexisting microphenocrysts, groundmass clinopyroxenes of basaltic rocks have a lower Mg to Fe ratio; higher contents of Al, Ti and Mn; and considerably lower Cr abundances. Microlites enclosed in more differentiated lavas show subtle chemical differences being higher in Fe and sometimes

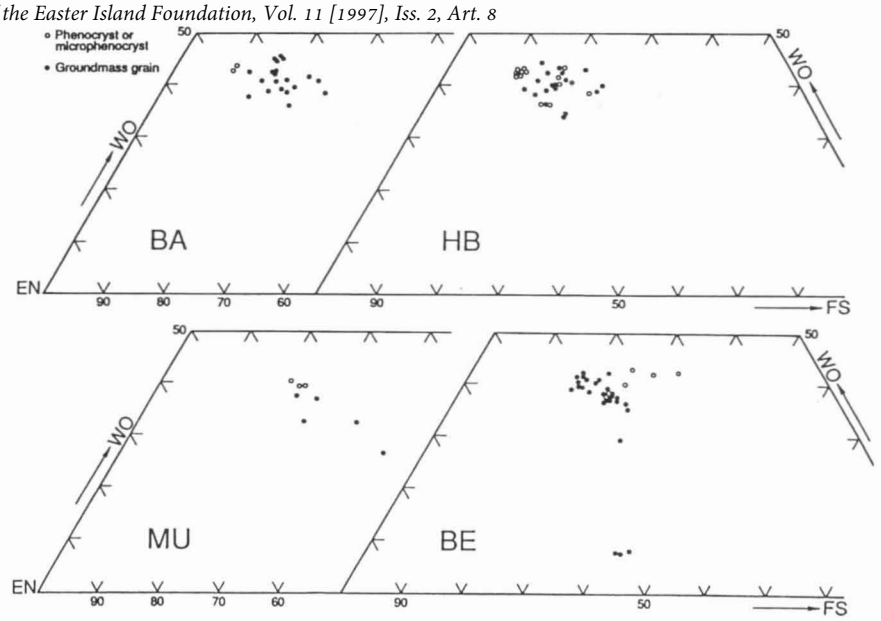

Figure 5. Compositional variations in pyroxenes from various lavas from Easter Island plotted on the pyroxene quadrilateral. Abbreviations as in fig.3.

Table 2
Representative analyses (in wt.%) of pyroxenes from various rocks from Easter Island

	a	b	c	d	e	f
SiO_2	52.07	51.43	51.20	49.66	50.08	52.07
TiO_2	0.40	0.53	0.65	1.46	-	0.30
Al_2O_3	3.06	5.65	1.58	1.76	1.08	0.45
FeO	6.02	7.00	14.59	15.13	20.10	24.84
MnO	0.15	0.27	0.57	0.59	0.73	0.99
Cr_2O_3	0.75	0.11	0.09	0.12	0.01	-
MgO	16.54	14.75	12.43	11.34	7.99	17.83
CaO	20.75	19.95	18.90	18.74	20.41	3.87
Na_2O	0.26	0.60	0.29	0.34	0.29	0.12
K_2O	-	0.06	-	0.14	-	-
Total	100.00	100.35	100.30	99.28	100.69	100.47
numbers of ions on the basis of 6 oxygens						
Si	1.91	1.88	1.94	1.92	1.96	1.98
Ti	0.01	0.01	0.02	0.04	-	0.01
Al	0.13	.024	0.07	0.08	0.05	0.02
Fe^{2+}	0.18	0.21	0.46	0.49	0.67	0.79
Mn		0.01	0.02	0.02	0.02	0.03
Cr	0.02	-	-	-	-	-
Mg	0.91	0.81	0.70	0.65	0.47	1.01
Ca	0.82	0.78	0.77	0.78	0.85	0.16
Na	0.02	0.04	0.02	0.03	0.02	0.01
K	-	-	-	0.01	-	-
Sum Mg	47.4	44.5	36.0	33.7	23.3	50.8
Sum Fe	9.9	12.3	24.6	26.2	34.0	41.3
Sum Ca	42.7	43.2	39.4	40.1	42.7	7.9

a. Endiopside microphenocryst in olivine tholeiite RN105
b. Augite microphenocryst in hawaiitic basalt RN58
c. Augite microphenocryst in mugearite RN89
d. Augite microphenocryst in benmoreite RN50
e. Ferroaugite microphenocryst in benmoreite RN13
f. Pigeonite microlite in benmoreite RN49
Dashes mean below detection limits

associated with in-termediate pigeonite.

Olivine compositions in relation to rock typology are illustrated in fig.6. A very substantial overall composition variation is displayed with olivine microphenocrysts and groundmass grains becoming progressively richer in iron in the more fractionated members of the rock series (Table 3). The most magnesium-rich olivines, with up to 84 per cent of the forsterite component, occur in basalts s.s. whereas ferrohortonolite and, much more exceptionally, fayalite are characteristic of benmoreitic flows. Olivines with strongly contrasting compo-sitions are reported from the benmoreite sampled at Vinapu (RN50). They provide additional mineralogical evidence for the hypothesis that this rock derives from the mixing of two mag-matic liquids. This model is also consistent with data obtained for the two chemically distinctive glass phases appearing in this specimen. At some places in the rock the glass is obviously rhyolitic, whilst at others it has a well settled tra-chytic composition (Table 4).

Titanomagnetite and ilmenite are the most widespread ore minerals. They may be associated with Cr-magnetite. Basaltic rocks contain ilmenite and titanomagnetite in varying proportions but it appears that ilmenite is much less common in differentiated rock types.

In parallel with the study of the various minerals, electron microprobe analysis was used to determine the composition of the glasses that build the moderately indurated sideromelane tuffs of Rano Raraku and the compact zeolitic palagonite tuffs cropping out at the top and along the steep slopes of Maunga Toa Toa. Quantitative inspection of major element compositions of several non-vesicular unaltered glass shards composing the hyaloclastitic rocks exposed along the southeastern slopes and cliffs of Rano Raraku indicate that the latter result from quenching of mugearitic lava outflows (Table 5). Moreover, it seems that there is a remarkable similarity between the chemistry of the analysed glass shards and the holocrystalline lapilli and lava fragments, measuring up to several decimeters

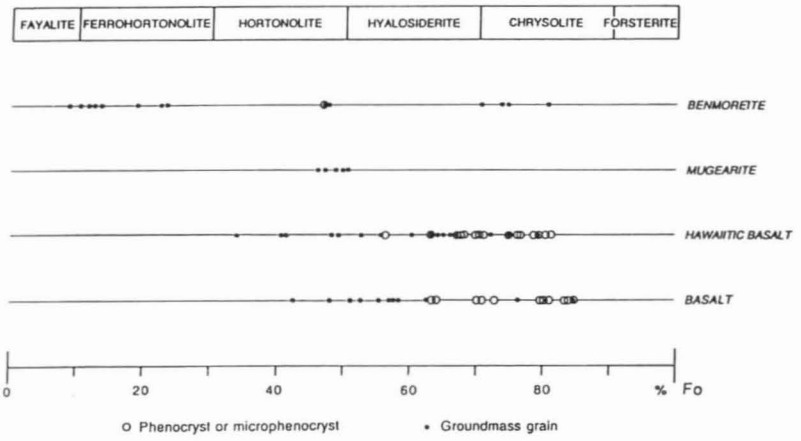

Figure 6. Compositional variations in olivines from various lavas from Easter Island. Nomenclature of olivines is according to Deer et al. (1982)

across, that occur scattered throughout the sidero-melane-rich deposits constituting this volcano. According to Baker (1993) Rano Raraku is a composite cone which is built by tuffs originating in at least two different craters.

The yellowish brown, reddish brown and orange rocks that built Maunga Toa Toa are commonly chabazite-cemented. The authigenic zeolites coat sideromelane shards that show conversion to gel-palagonite or fibrous palagonite. The palagonitic zones are often separated from the unaltered glass by zones with finely divided Fe- and Ti-oxides. Angular vesicle-free sideromelane lapilli coming from Maunga Toa Toa have a Differentiation index close to 27 and a normative plagioclase containing on the average about 52 per cent anorthite (Table 6, anal. a and b). They are thus chemical equivalent to basalt s.s. and therefore do not derive from the same volcanic events as the ones responsible for the construction of Rano Raraku. Additional microprobe investigation was performed on sideromelane and juxtaposed palagonite in order to study the relative mobility of various major elements during palagonitization (Table 6, anal.c to f). Analyses of chabazite crystals cementing a palagonite tuff specimen coming from the same lo-cality are given in Table 7.

Table 3.
Representative analyses (in wt.%) of olivines from various rocks from Easter Island

	a	b	c	d	e	f
SiO_2	39.91	39.19	34.61	34.50	29.80	30.27
TiO_2	0.24	0.09	0.13	0.08	0.23	-
Al_2O_3	0.03	0.07	0.08	0.03	-	0.02
FeO	14.81	19.17	41.26	42.47	62.11	64.66
MnO	0.12	0.21	0.78	0.98	2.08	1.95
Cr_2O_3	0.11	0.03	0.03	0.11	0.02	0.01
MgO	44.12	41.37	22.65	21.59	5.10	3.61
CaO	-	0.19	0.35	0.20	0.32	0.27
Na_2O	0.03	0.01	0.07	0.01	0.13	0.06
K_2O	0.04	-	0.01	-	0.01	0.03
Total	99.41	100.33	99.97	99.97	99.80	100.97
numbers of ions on the basis of 4 oxygens						
Si	1.01	1.00	1.00	1.00	0.98	1.00
Ti	-	-	-	-	0.01	-
Fe^{2+}	0.31	0.41	0.99	1.03	1.71	1.77
Mn	-	-	0.02	0.02	0.06	0.05
Mg	1.66	1.57	0.97	0.93	0.25	0.18
Ca	-	0.01	0.01	0.01	0.01	0.01
Na	-	-	-	-	0.01	-
mg	0.84	0.79	0.49	0.47	0.12	0.09

a. Crysolite microphenocryst in olivine tholeiite RN10
b. Crysolite microphenocryst in hawaiitic basalt RN9
c. Hortonolite microlite in mugearite RN89
d. Hortonolite microphenocryst in benmoreite RN50
e. Ferrohortonolite microlite in benmoreite RN13
f. Fayalite microlite in benmoreite RN13
Dashes mean below detection limits

Major, trace and RE element contents

As we already mentioned in Section 2., the volcanic eruptions that occurred on Easter Island produced large proportions of basic rocks but rather few of intermediate or silicic compositions. To facilitate the visual appreciation of the geochemical coherence existing between the 57 lavas analysed within the framework of the present study, it was useful to compute the average chemical compositions of the different rock types (Table 8) and to plot the elemental abundances refering to each rock type against an appropiate fractionation index.

A variation diagram in which weight per cents of oxides of major elements are plotted against the Solidification Index of Kuno is illustrated in fig.7. Note the particularly good correlation between the solidification index and MgO so that any variation diagram employing MgO as abscissa would convey almost exactly the same graphical information. In fig.8 concentrations expressed in parts per million of eleven trace elements are shown as a function of the same index. The smoothness of the different curves shown in both bivariate plots suggest that most if not all rock specimens analysed are likely to be cogenetic and may derive from a process of crystal fractionation in closed system.

Both figures are very effective to discriminate elements that are preferen-

Table 4.
Representative analyses (in wt.%) and normative mineralogy of glass phases in benmoreite RN50; compositions are recalculated to 100% H_2O-free

	a	b
SiO_2	72.92	63.15
TiO_2	0.63	0.10
Al_2O_3	12.83	21.64
FeO	4.63	1.42
MnO	0.09	0.04
MgO	0.12	0.05
CaO	0.75	4.52
Na_2O	4.96	7.95
K_2O	3.07	1.13
CIPW norms (in wt.%)		
q	27.93	2.44
or	18.15	6.68
ab	41.95	67.28
an	3.70	20.03
di	0.02	2.12
hy	6.01	0.94
mt	1.11	0.32
il	1.20	0.20
DI	88.0	74.0
Plag.(%An)	8.1	22.9

a. Glass phase 1 (average of 22 points)
b. Glass phase 2 (average of 2 points)
compositions are recalculated to100% H_2O-free

Table 5
Chemical and normative compositions of lava blocks and glass shards from Rano Raraku tuffs; major elements are recalculated to 100% H_2O free

	a	b	c	d	e	f
major elements in weight %						
SiO_2	53.93	54.30	55.40	55.24	54.30	51.33
TiO_2	2.33	1.92	2.04	2.08	1.99	2.62
Al_2O_3	14.03	14.02	14.53	13.75	14.16	14.10
Fe_2O_3	14.24	14.71	13.58	14.54	14.35	14.31
MnO	0.36	0.37	0.26	0.30	0.30	0.26
MgO	3.04	3.03	2.82	3.14	2.17	3.39
CaO	7.40	6.85	6.90	6.66	6.33	7.51
Na_2O	3.32	3.39	3.28	2.98	4.20	3.90
K_2O	1.35	1.27	1.19	1.31	1.34	1.28
P_2O_5	-	-	-	-	0.86	1.29
Cr_2O_3	-	0.16	-	-	-	-
CIPW norms in weight %						
q	5.94	6.30	8.95	9.51	5.26	1.97
or	7.96	7.51	7.01	7.74	7.90	7.57
ab	28.11	28.69	27.74	25.22	35.56	32.99
an	19.39	19.28	21.42	20.28	15.83	17.19
di	14.68	12.47	10.85	10.82	8.98	10.50
hy	15.20	17.44	16.04	18.10	16.48	17.65
mt	3.10	3.20	2.96	3.17	3.13	3.10
ilm	4.43	3.64	3.87	3.95	3.78	4.98
ap					2.05	3.06
chr		0.25				
DI	42.01	42.50	43.70	42.47	48.72	42.53
Norm. Plag.An%	40.8	40.2	43.6	44.6	30.8	34.3

a. Glass shard in sideromelane tuff RN94
b. Glass shard in sideromelane tuff RN94
c. Glass shard in sideromelane tuff RN97
d. Glass shard in sideromelane tuff RN97
e. Lava block RN88 in sideromelane tuff
f. Lava block RN91 in sideromelane tuff

Table 6
Chemical compositions of glass shards and associated palagonite in a chabazitic palagonite tuff from Maunga Toa Toa (RN64);

	a	b	c	d	e	f
major elements in weight %						
SiO_2	49.16	48.80	46.21	45.50	43.85	40.51
TiO_2	2.18	1.88	3.91	4.01	3.91	7.50
Al_2O_3	15.10	15.07	9.35	8.89	7.97	5.28
Fe_2O_3	11.89	11.79	13.99	15.63	22.07	28.40
MnO	0.22	0.07	0.23	0.26	0.30	0.37
MgO	6.75	6.58	1.06	1.15	1.14	3.75
CaO	10.57	10.21	9.45	9.29	6.86	2.20
Na_2O	2.92	3.03	0.12	0.14	0.30	0.15
K_2O	0.53	0.36	0.25	-	0.22	-
Cr_2O_3	0.09	0.01	-	0.02	0.12	0.01
CIPW norms in weight %						
or	3.12	2.12				
ab	24.70	25.64				
an	26.54	26.46				
di	21.26	19.82				
hy	9.17	10.63				
ol	6.72	5.98				
mt	2.57	2.27				
ilm	4.14	3.57				
chr	0.13	0.02				
DI	27.82	27.76				
Norm.Plag.An %	51.8	50.8				

a. Unaltered glass shard
b. Unaltered glass shard
c. Yellowish palagonite in unaltered glass shard
d. Yellowish-brown palagonite in unaltered glass shard
e. Dark brown zone at the interface between unaltered glass and palagonite
f. Dark brown to opaque zone in yellowish palagonite

tially concentrated in the liquid phase during crystallization (incompatible elements) from those preferentially extracted in the crystallizing solid phases (compatible elements). The trends obtained graphically are in very good agreement with those noted previously. However, they suppress the scatter recorded for several trace elements. Nickel, for instance, is subject to very strong scatter in basalts s.s. as values range from hardly 15 to 152 ppm. It seems that Ni contents higher than 50 ppm are an exclusivity of lava flows from the Roiho region.

The chondrite-normalized REE patterns of all analysed basaltic rocks from Easter Island are typified by light-REE enrichment relative to the heavy REE (fig.9). Such patterns are known to be consistent with a mantle plume source derivation and reflect relatively small degrees of partial melting of a source in which garnet remains as a residual phase. Crystal fractionation involving olivine, plagioclase, clinopyro-xene and Fe-Ti oxides increases the total REE content of more evolved rock types (hawaiite, mugearite, benmoreite, comendite) but does not produce any significant interelement fractionation. Hence, the characteristic shape of the basalt REE pattern is maintained, while absolute abundances increase notably. Substantial plagioclase fractionation leads to small negative europium anomalies in the comenditic rhyolites.

Trace and RE element abundances of average tholeiitic basalt, hawaiitic basalt, hawaiite, mugearite, benmoreite and comenditic rhyolite from Easter Island normalized to primitive terrestrial mantle values are plotted in fig.10. Normalizing values used are those recommended by Sun (1982) and Sun & Mc-Donough (1989). In this spider diagram elements are ordered from left to right in sequence of decreasing incompatibility in a four-phase lherzolite undergoing partial fusion,

Table 7
Compositions (in wt.%) of chabazite crystals from palagonite tuff RN64 from Maunga Toa Toa

	a	b	c	d	e
major elements in weight %					
SiO_2	51.42	50.45	48.35	51.04	49.86
Al_2O_3	20.88	20.62	21.77	22.16	21.42
Fe_2O_3	0.03	0.18	0.13	0.17	0.12
MnO	0.06	-	-	-	-
MgO	0.30	0.23	0.23	0.24	0.13
CaO	10.62	9.61	10.54	10.10	10.52
Na_2O	1.47	2.09	2.41	3.27	4.59
K_2O	0.04	0.28	0.06	0.04	0.52
Cr_2O_3	0.04	-	-	-	-
Total	84.86	83.46	83.49	87.02	87.18
numbers of ions on the basis of 72 oxygens					
Si	24.17	24.15	23.31	23.58	23.31
Al	11.57	11.63	12.37	12.07	11.81
Fe^{3+}	0.01	0.06	0.05	0.06	0.05
Mn	0.02	0.00	0.00	0.00	0.00
Mg	0.21	0.16	0.17	0.17	0.09
Ca	5.35	4.93	5.44	5.00	5.27
Na	1.34	1.94	2.25	2.93	4.16
K	0.02	0.17	0.03	0.22	0.31
H_2O	23.70	26.40	26.54	20.00	19.99
Z	35.75	35.84	35.73	35.71	35.17
R	6.92	7.20	7.89	8.32	9.83

$Z = Si+Al+Fe^{3+}$
$R = Mg+Na+Ca+Sr+K+Ba$

and peaks and troughs shown by the different curves reflect the distinctive signature of a particular fractionated mineral or mechanism of differentiation.

The primitive mantle-normalized pattern of the average Easter Island basalt has a relatively smooth convex shape. More evolved rocks are characterized by broadly similar configurations but as fractionation proceeds the patterns show distinctive negative spikes at Sr-P, Ti and V. Both the magnitude of the spikes and the degree of incompatible element enrichment increase progressively with crystal fractionation and REE enrichment. An interesting feature is the marked trough at Sr-P. Sr remains almost constant until a relatively late stage, when it is depleted as result of fractional crystallization of plagioclase. P concentrations first increase, then decrease, when apatite starts to crystallize. Ti and V behave in a simi-lar manner and their concentrations are controlled by Fe-Ti oxides. The poorly marked inflection at Ba has probably also to be brought into relation with crystallization of plagioclase feldspar.

Three rock specimens of basaltic composition (RN103, RN104 and RN105) collected in the vicinity of Cabo Cumming, downhill the eastern slopes of the Poike, and a benmoreitic flow (RN50) cropping out south of Vinapu, in the

Table 8
Chemical composition (major elements in wt.% and recalculated to 100% H_2O free; trace and RE elements in ppm) and CIPW norms (in wt.%) of the principal rock types from Easter Island

	a	b	c	d	e	f
SiO_2	47.87	48.33	51.34	52.22	60.43	73.26
TiO_2	2.89	3.35	2.62	2.17	1.34	0.20
Al_2O_3	16.82	15.70	14.10	15.40	14.64	12.94
Fe_2O_3	12.76	13.99	14.31	13.56	10.22	3.26
MnO	0.20	0.21	0.26	0.25	0.22	0.07
MgO	5.59	4.80	3.39	2.84	1.40	0.02
CaO	10.12	9.20	7.51	6.79	4.21	0.66
Na_2O	2.96	3.27	3.90	4.28	4.92	5.74
K_2O	0.39	0.68	1.28	1.40	2.15	3.82
P_2O_5	0.40	0.47	1.29	1.09	0.47	0.03
q				3.21	9.94	23.87
or	2.28	4.01	7.57	7.74	12.69	22.60
ab	25.07	27.69	32.99	35.14	41.64	45.26
an	31.46	26.15	17.19	17.22	11.52	
ac						1.43
ns						0.39
di	13.50	13.89	10.50	8.64	5.68	2.77
hy	12.61	13.14	17.83	17.40	11.87	2.97
ol	4.84	3.61				
mt	2.78	2.73	2.80	2.76	2.22	
il	5.49	6.36	4.98	4.17	2.55	0.38
ap	0.94	1.11	3.05	2.52	1.11	0.07
Rb	5.2	9.8	21.3	25.4	36.9	78.7
Sr	313.6	302.0	275.0	279.0	196.0	24.8
Ba	125.6	151.4	186.0	239.3	322.0	469.7
Sc	32.3	32.9	25.3	25.4	18.4	0.5
V	295.4	325.0	124.0	62.0	58.0	3.0
Cr	97.3	56.3	3.0	3.0	5.3	2.0
Co	40.8	40.4	22.0	16.3	11.0	1.0
Ni	57.8	34.9	2.0	2.0	4.7	2.0
Y	41.2†	52.1	85.0	91.3	89.2‡	156.7
Zr	211.8	257.7	393.0	466.0	710.0	753.7
Nb	26.7	33.4	44.5	47.7	71.2	110.3
La	22.9†	29.1	40.3	45.3	49.5‡	92.0
Nd	32.3†	39.4	64.7	65.9	63.5‡	101.0
Eu	2.5†	3.0	4.7	4.7	4.6‡	3.8
Dy	7.4†	9.2	14.8	15.4	15.3‡	25.1
Er	3.9†	4.7	7.2	8.2	8.5‡	14.8
Yb	3.3†	4.2	6.4	7.0	8.2‡	13.6
DI	27.4	31.7	42.5	46.1	64.3	91.7
Plag. %An	55.7	48.6	34.3	32.9	21.7	0

a. Tholeiitic basalt (average of 9)
b. Hawaiitic basalt (average of 38)
c. Hawaiite (1 sample)
d. Mugearite (average of 3)
e. Benmoreite (average of 3)
f. Comendite (average of 3)
*Total Fe as Fe2O3
† RN103, RN104 and RN105 excluded
‡ RN50 excluded

Table 9

Major, trace and REE abundances in four lavas from Poike and Rano Kau; major elements are recalculated to 100% H_2O free

	a	b	c	d
major elements in weight %				
SiO_2	48.69	48.56	48.75	61.46
TiO_2	3.22	2.14	2.18	1.45
Al_2O_3	16.00	19.94	19.73	14.46
Fe_2O_3	14.17	10.03	10.16	9.38
MnO	0.20	0.24	0.18	0.21
MgO	4.61	4.70	4.46	1.59
CaO	9.44	11.37	11.30	4.18
Na_2O	3.08	2.66	2.83	4.55
K_2O	0.23	0.09	0.14	2.31
P_2O_5	0.40	0.27	0.27	0.41
trace elements in ppm				
Rb	2.9	2.0	2.9	40.2
Sr	297	315	325	180
Ba	178	75.0	98.0	344
Sc	37.2	30.1	31.0	16.2
V	341	239	244	83.0
Cr	35.0	127	134	6.0
Co	42.0	34.0	34.0	15.0
Ni	37.0	41	42.0	5.0
Y	293	203	312	1990
Zr	217	137	143	704
Nb	27.4	17.2	17.7	73.3
RE elements in ppm				
La	125	55.1	90.3	729
Nd	181	67.3	123	995
Eu	15.4	6.8	11.8	61.2
Dy	55.6	32.3	50.7	297
Er	31.9	21.8	32.0	170
Yb	31.9	18.6	32.2	175

a. Tholeiitic basalt from Cabo Cumming, Poike (RN103)
b. Tholeiitic basalt from Cabo Cumming, Poike (RN104)
c. Tholeiitic basalt from Cabo Cumming, Poike (RN105)
d. Benmoreite from Vinapu, Rano Kau (RN50)

northeastern part of Rano Kau, are strongly enriched in REEs and yttrium relative to other incompatible elements (Table 9). As pinpointed in Table 8, these specimens were disregarded at the mo-ment of calculating the average REE and Y contents of the tho-leiitic basalts and benmoreites. The chondrite-normalized REE patterns displayed by these four unusual rocks have a characteristic shape due to unfractionated heavy REE abundances. They are essentially flat, with a slight tendency towards light REE enrichment and a maximum light REE enrichment of more than 2200 times chondrite for the benmoreite (fig.11). The Y enrichment noted for the same benmoreitic rock specimen ap-proximates 1000 times chondrite.

Fig.12 emphasizes both the similarity of the primitive mantle-normalized patterns of the three geochemically unusual basalts from the Poike and the striking difference of the latter with the smooth convex curves obtained for the remainingbasaltic rocks from Easter Island (fig.10). The benmoreiteRN50 shows obviously a still more 'spiked' incompatible trace element pattern with prominent negative peaks at Sr, Ti and V.

There are several reports of oceanic island basalts from the Pacific that are enriched in REEs and Y relative to other incompatibleelements (HawaiianIslands, Norfolk Island) (Fodor et al., 1987; Green, 1978). In more exceptional cases the unusually high REE contents are associated with anomalously high concentrations of Co, Mn and Cr (Tahaa volcano, French Polynesia) (Joron et al. 1991: Schiano et al. n.d.). Microprobe studies revealed that post-magmatic alteration, resulting in the formation of REE-rich carbonates, phosphates or hydroxides of secondary origin, may sometimes be responsible for such unusual REE and yttrium enrichments (Nagashima et al. 1986; Fodor et al. 1987). Unfortunately, none of these minerals could be detected during the detailed microprobe analysis of rock sample RN50 from Easter Island, which displays by far the strongest enrichment among all samples available for the present study.

Conclusions

The major conclusions of this study, that is based on 60 selected rock samples collected chiefly in the eastern part of Easter Island, are:

(1). The petrographic signatures and whole-rock elemental compositions of all analysed specimens are closely comparable with data already described by other workers. In consequence they broadly support previous hypotheses regarding derivation and evolution of the magmatism on the island.

(2). About 400 microprobe analyses of silicate and oxide mineral phases, and natural glasses provide new clues about the phase chemistry of the various lava types occurring on the island and illustrate the compositional variations of phenocrysts/ microphenocrysts and groundmass grains during the evolving magma chemistry.

(3). The finding that several outcrops of basaltic and more differentiated lavas are unusually enriched in REEs and Y relative to other incompatible elements shows that the regional extent of such rocks is not an exclusivety of some rare island groups in the western and central part of the Pacific and thus points to petrogenetic processes acting on a large, worldwide scale.

(4). Microanalysis of glass shards embedded in sideromelane tuffs from Rano Raraku and in palagonite tuffs from nearby Maunga Toa Toa refutes the idea that, despite lithological similarities, both edifices were built during the same magmatic event.

* Department of Geology and Soil Science, Gent University, Krijgslaan 281, B-9000 Gent (Belgium)

† Anton de Kom University of Suriname, Faculty of Technological Sciences, Leysweg, POP 9212, Paramaribo (Suriname)

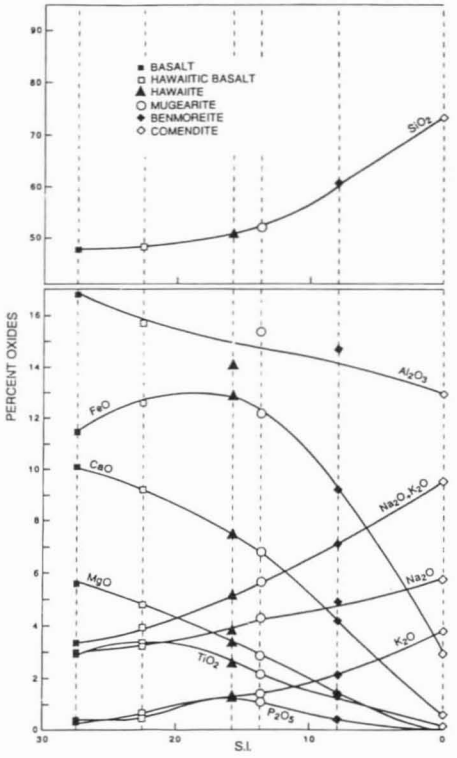

Figure 7. Weight per cents of oxides of nine major elements plotted against SI for the whole-rock compositions of Table 8.

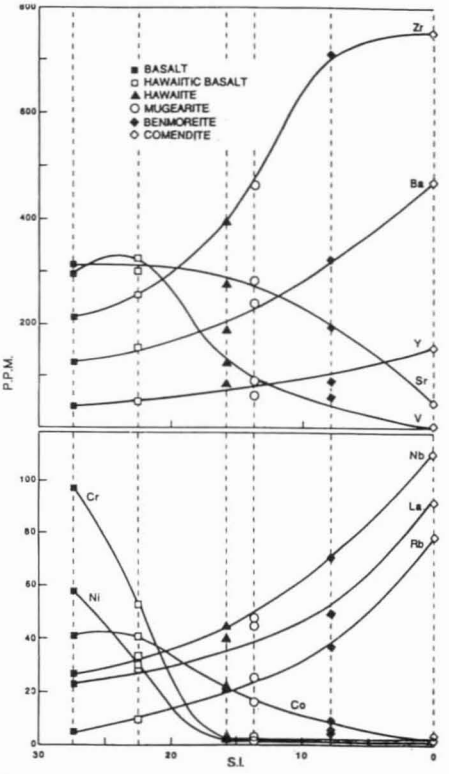

Figure 8. Concentrations (in ppm) of eleven trace elements plotted against SI for the whole-rock compositions of Table 8.

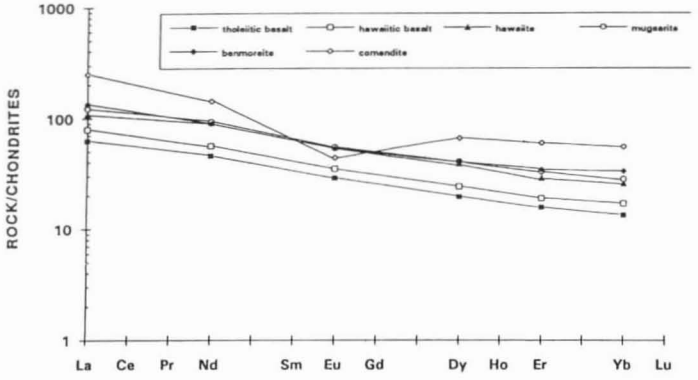

Figure 9. REE concentrations in the whole-rock compositions of Table 8, normalized to chondritic values.

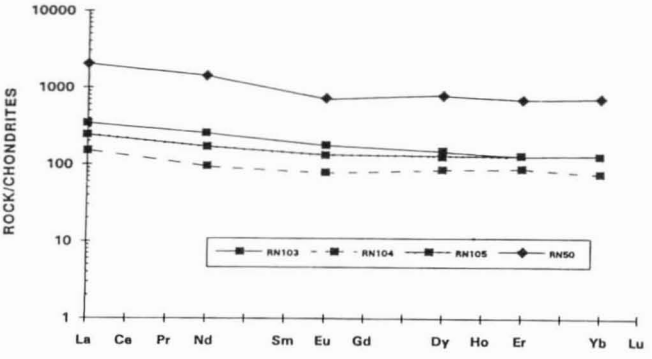

Figure 11. REE concentrations in 4 lavas from Poike (RN103, RN104, RN105) and Rano Kau (RN50), normalized to chondritic values

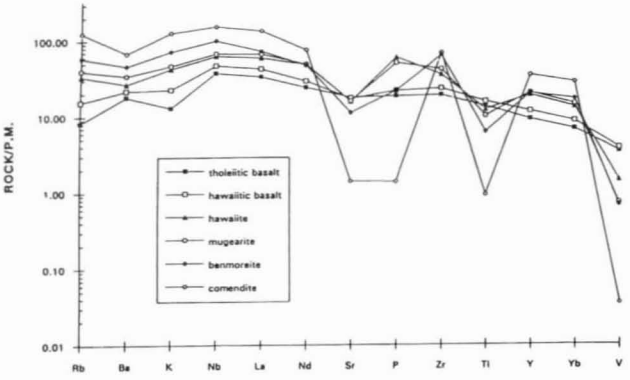

Figure 10. Trace and REE concentrations in the whole-rock compositions of Table 8, normalized to the composition of the primordial terrestrial mantle. The normalizing values are those of Sun & Mc-Donough (1989).

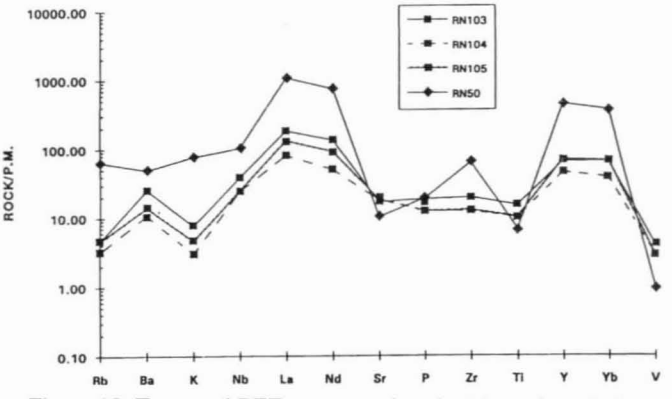

Figure 12. Trace and REE concentrations in 4 lavas from Poike (RN103, RN104, RN105) and Rano Kau (RN50), normalized to the composition of the primordial mantle. The normalizing values are those of Sun & McDonough (1989).